"On a Remarkable Effect produced by the Momentary Relief of Great Pressure." By J. Y. Buchanan, F.R.S. Received May 14,—Read May 28, 1903.

[Plates 1 and 2.]

The effect is shown in the brass tube and the copper sphere which I have the honour to exhibit to the Society. It is also illustrated in figures 1—4 which accompany this paper.

The experiment was made for the first time on board the "Challenger" in the early part of the cruise. At that time the deep sea thermometers, with protected bulb, had only been recently introduced, and the effect of pressure on thermometer bulbs, whether protected or not, occupied public attention. In the deepest sounding made by the "Challenger" in the Atlantic, namely, that of March 26, 1873, when a depth of 3875 fathoms was reached, both the thermometers, which were sent to the bottom, collapsed. It, therefore, became a question what recommendation should be made to the thermometer makers to assist them in producing thermometers which shall be able to withstand the greatest pressure to which they are likely to be exposed in the work of ocean sounding.

For this purpose I immediately prepared the following experiment:—I took glass tubes of three different calibres. The widest had about the calibre of the outer bulb of a *Millar-Casella* thermometer, the narrowest had an internal diameter of 6 mm., and the third had a diameter of about 10 mm. A length of 75 mm. of each was sealed up at both ends, and the three tubes were wrapped in a cloth and enclosed in the cylindrical copper case of a deep-sea thermometer.

The upper and lower ends of these cases are pierced with many holes in order to permit the passage of water through them. On the next day, March 27, 1873, the case was attached to the sounding line and a depth of about 2800 fathoms was reached. When the case came up again it looked as if someone had struck it in the middle with a hammer. When it was opened and the cloth unfolded, it seemed for a moment as if it were full of snow, but a second look showed that what appeared to be snow was nothing but finely comminuted glass. The two wider tubes had collapsed, but the narrow one was intact. At first sight the effect produced on the copper case was puzzling, but after a little study and reflection its nature became apparent.

No account of the experiment has been published, and when I was able, through the kindness of H.S.H. the Prince of Monaco, to join his yacht the "Princesse Alice" for her cruise of last summer, I determined to repeat it, and, if possible, to vary it. Owing to press of

other work, nothing was done until near the end of the cruise. The brass tube (figs. 1 and 2, Plate 1) above referred to, was the case for holding a piezometer which was accidentally broken. With it I repeated the experiment which I had made in the "Challenger," with this difference, that I used only one sealed glass tube. It was an ordinary pipette of 50 c.c., sealed up at both ends close to the body. It was wrapped in a piece of muslin and loosely packed with cotton waste so as to occupy the middle of the brass tube.

The length of the brass tube was 33 cm., and its diameter 4·13 cm. Its weight without the cover was 350 grammes. Both the top and the bottom are pierced with many holes so as to allow passage to the water.

Thus charged, it descended on the sounding line to a depth of 3000 metres, and when it came up it was evident from its appearance that the experiment had succeeded. As in the experiment on board the "Challenger," the glass tube had been converted into a snow-white powder. The external effect also was confined entirely to that part of the brass tube which had been occupied by the sealed glass tube. Above and below it there was no disfiguration.

The copper ball (figs. 3 and 4, Plate 2) is an ordinary 5-inch ball for the supply tap of a cistern. A spherical glass fractionating flask, having a diameter rather less than 1½ inch, was hermetically sealed close to the spherical body. It was then wrapped in a piece of muslin, and with loose packing of cotton waste it was enclosed between the two copper hemispheres, which were then soldered together. The holes at the poles of the copper sphere gave free communication with the sea water. The copper ball was then attached to the dredging cable, which took it to a depth of 3000 metres. When it came up no external effect was visible. I could not believe that even a small flask of the kind could support a pressure of 300 atmospheres, and I concluded that it had collapsed shortly after leaving the surface. Still, as the line was going to make a second excursion, and this time to 6000 metres, I re-attached the ball along with a larger one to it.

On returning to the surface the ball had the appearance which you see. If the soldered welt represent the equator, it will be seen that both polar areas are as they were. Perpendicularly to the equator a system of folds or creases runs northwards and southwards and extends very little beyond the tropics. The creasing is most accentuated at a part of the equator where there is a slight flattening. It is evident that the glass flask when it collapsed was relatively near this part of the ball. I did not open the ball, as I thought it would be more instructive to keep it as it is. The débris of the glass flask with the cotton waste is still inside it.

The effect of the sudden relief of pressure on the copper ball is

distributed much more uniformly over it than is the case in the brass tube. In the latter the effect is very powerful and very local. In both cases the effects which we see have been produced in a moment of time, and are properly speaking, the effects of violent shock. It is remarkable that in the ball the equatorial zone which has the welt to stiffen it should be the field of all the disfigurement, while the polar areas which have no strengthing have not been exposed, or at least have not yielded to strain.

If we examine the brass tube, figs. 1, 2, we see that, with the exception of the portion nearly in the middle which held the sealed glass tube, the case has perfectly preserved its cylindrical form. The distortion or crumpling affects only the part where the tube collapsed, and it is evident that it did not occupy a truly axial position, but lay nearer that part of the brass envelope where the ears for attachment to the sounding line are situated. Here a most formidable corrugation (fig. 1) has been produced, the metal being pinched into a fold so as almost to meet inside. Besides this, there are two minor corrugations. A greater thickness of water intervened between this part of the brass envelope and the enclosed glass tube, and the small effect produced shows that the difference of pressure within and without the brass tube was here comparatively small. It will be observed that the butt-joint of the tube has been opened at fig. 2; but this is a secondary effect due to the distortion.

The brass tube, as it stands, is a manometer or pressure gauge which records the distribution of pressure in it while filled with and immersed in water, during the instant of time when, while the pressure on all sides is very great, the pressure at a locality in the interior suddenly becomes nothing or very small. The effect of this sudden difference of pressure has been concentrated on the part of the brass tube nearest to which the glass tube was situated. Here the diminution of internal volume of the brass tube produced by the principal corrugation must, from rough measurements, be very nearly equal to that of the glass tube which collapsed. At first sight it appears remarkable that on the collapse of the glass tube, when it was free to the compressed sea water to fill up the void with water through the two open ends, instead of doing so, it filled it by pinching up the stout brass of which the tube was made, to such an extent as to obliterate the void.

The experiment shows us that it was easier in the time to pinch the envelope of brass than to shove in the plugs of water at both ends. The complete absence of distortion or disfigurement of the upper and lower portions of the brass tube shows that the tension of the water in these two portions of the tube was not materially diminished in the time between the collapse of the glass tube and the occupation of its place by the corrugation of the envelope. In considering this experiment, we must distinguish between the tension and the pressure of the

water. When the water is at rest they are equal. During a catastrophe of this kind the balance is destroyed, as in the case of air which is transmitting a sound wave. If water were incompressible, it could have no tension, however great the pressure to which it might be exposed. What pinched the brass tube was not the column of 2000 or 3000 metres subsiding on it, but the resilience of the unlimited supply of water in its neighbourhood at the high tension due to its compression by a pressure of 200 or 300 atmospheres. Relatively, this acts instantaneously; while, to put in motion a mass of water takes a definite time. The quantity of water contained in the brass tube is not sufficient for its resilience to produce any counter-vailing effect to the resilience of the mass of compressed sea water outside.

In the case of the copper sphere it is otherwise. Its diameter is 5 inches, that of the sealed glass bulb inside of it was between 1 and $1\frac{1}{2}$ inch, and certainly not greater than $1\frac{1}{2}$ inch. If we assume it to have been $1\frac{1}{2}$ inch, then its volume is to that of the copper sphere in the proportion $3^3 : 10^3 = 27 : 1000$. If we assume that the glass bulb succumbed at a depth of 5000 metres, or at a pressure of 500 atmospheres, then the resilience of the water inside of the copper sphere would have a very considerable effect in neutralising the crushing action of the water outside. At the low temperature found at great depths in the ocean the volume of a mass of distilled water is compressed by 2·5 per cent. by a pressure of 500 atmospheres. The compressibility of sea water is nine-tenths of that of distilled water, therefore, it would be compressed by 2·25 per cent. The compression produced by a pressure of 500 atmospheres is equal to the expansion when the pressure is diminished by the same amount. But the volume of the glass bulb was not greater than 2·7 per cent. of that of the copper sphere, and it was probably less; therefore the water in the copper sphere would, at the moment of the collapse of the glass sphere, expand by very nearly the volume of the collapsed bulb, and the copper ball would then be filled, for the moment, with water having a tension equal to about atmospheric pressure. Its tension would then be brought up to 500 atmospheres by the entry of water through the holes at the two poles. The expansion of the mass of compressed water in the copper sphere takes off from the suddenness of the action, while it at the same time reduces, by at least one-half, the difference of pressures outside and inside the sphere at the instant of collapse, and this is the agent which deforms the metal sphere.

By altering the relation between the volume of the copper sphere and that of the glass sphere enclosed in it and the pressure to which the system is exposed, the effect produced may be varied at will. When experimenting in the sea, the volume of the compressed water outside of the copper sphere is practically infinite. If it is sought to reproduce these effects in the laboratory, then a very large pressure

vessel must be used. If a pressure vessel of limited size be used and, altering the experiment, if the hermetically sealed glass sphere and the copper sphere with its polar perforations be placed in it separately, then when the pressure is raised to such a point that the glass sphere collapses, the copper sphere will burst outwards.

I was profoundly impressed at the time by the experiments which I made on board the "Challenger," and I connected them with another experiment which is familiar to chemists. When substances are set to react upon one another in a sealed tube, there is frequently disengagement of gas which produces a very high tension in the interior of the tube even when cold. If it is sought to open the tube by breaking off the sealed point, an explosion is almost sure to take place. This may have very serious consequences, and yet it has been produced by a *relief* of pressure. These examples of the destructive effect which can be produced by the sudden relief of pressure led me to believe that many shocks of earthquake may be due to similar relief of subterraneous pressure.

These experiments, whether made with the copper ball or with the brass tube, furnish striking demonstrations of the importance of the element of *time* in all physical considerations.

The collapse of the brass tube, under the peculiar circumstances of the experiment, is the exact counterpart of the experiment which is frequently, but unintentionally, made by people out shooting, especially in winter. If, from inattention or other cause, the muzzle of the gun gets stopped with a plug of even the lightest snow, the gun, if fired with this plug in its muzzle, invariably bursts. Light as the plug of snow is, it requires a definite time for a finite pressure, however great, to get it under way. During this short time the tension of the powder gases becomes so great that the barrel of the ordinary fowling-piece is unable to withstand it and it bursts.

Fig. 1.

Fig. 2.

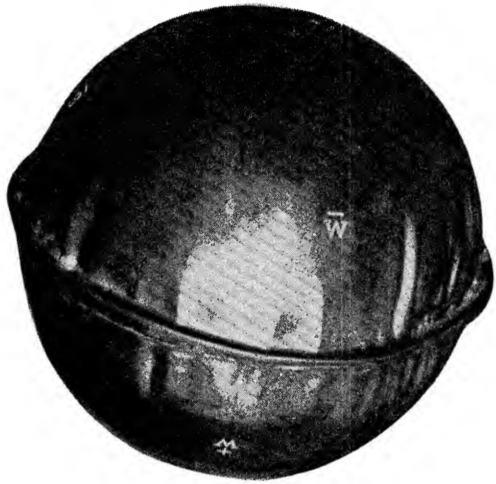

Fig. 3.

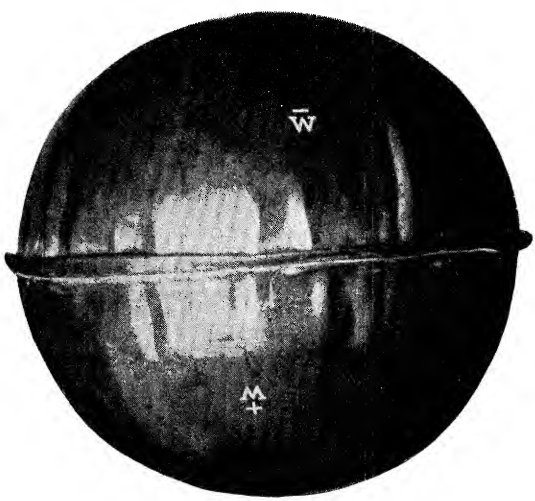

Fig. 4.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.